Calibrated Modelling of Form-Active Hybrid Structures Smart Geometry 2016 Cluster Proposal

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Fig 1: Interior photo of Hybrid Tower. A 9m tall form-active hybrid structure (CITA/KET 2015)

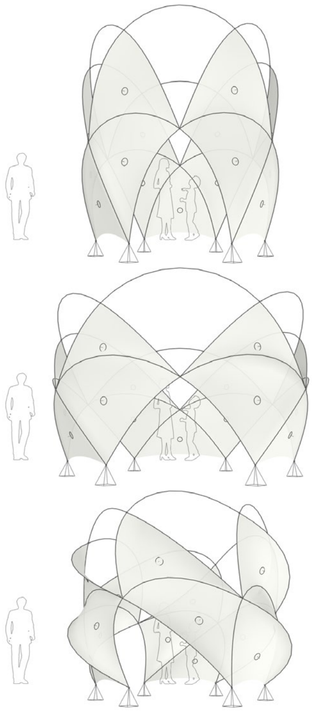

Fig 2: Interactive shaping and dimensioning pipeline using Joey/Kangaroo2 (CITA 2015)

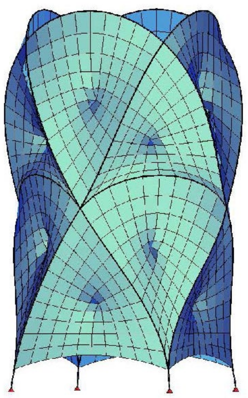

Fig 3: Finite Element form-finding and structural analysis using SOFiSTiK (KET 2015)

1. Research Question

How can we implement projection based dynamic relaxation methods to unlock the latent potential of form-active hybrid structures?

Form-active hybrid structures couple two or more different structural elements with low stiffness (such as slender beams, cables and membranes) into one structural assembly of high stiffness. They offer high load-bearing capacity at a fraction of the weight of traditional building elements and do so with a clear aesthetic expression of force flow and equilibrium. The exploration and development of form-active hybrid structures is important because of their potential to improve the performance of buildings in terms of efficiency of material usage.

The design of hybrid structures is limited by one significant restriction: The geometry definition, form-finding and structural analysis are typically performed in separate and bespoke software packages which introduce interruptions and data exchange issues in the modelling pipeline. This interdependent behaviour adds substantial complexity to the process of design which typically limits hybrid structures to simple topologies (e.g. membrane restrained column/arch (2)). The full potential of hybrid structures can only be unlocked with a tool which simultaneously facilitates their design in a geometrically flexible environment (i.e. Grasshopper) and which provides immediate feedback to the designer in terms of structural performance (i.e. Kangaroo2).

The mechanical precision, stability and open software architecture of Kangaroo2 has facilitated the development of proof-of-concept modelling pipelines which can tackle this challenge and offer a powerful form of materially-informed sketching. We invite cluster participants to explore this new modelling paradigm, to evaluate its output in terms of mechanically correct engineering behaviour and to design, develop and prototype novel hybrid structures.

2. Cluster Goals

The overall goal of the cluster is to disseminate the knowledge and methods needed to explore and develop novel form-active hybrid structures. More specifically this can be summarised as learning goals for the participants and expected outcomes of the cluster for exhibition and dissemination:

Structural Principles:
- Projection based dynamic relaxation with real-world mechanical properties.
- Structural behaviour: Axial, bending and membrane stiffness.
- Engineering output: Reactions, stresses and deflections.

Computational Modelling Principles:
- Kangaroo2 Basics: Modelling hybrid structures using standard components.
- Kangaroo2 Calibration: Implementing real-world material properties.
- Kangaroo2 Scripting: Using GHPython/C# to develop custom pipelines, goals and solvers.

Exhibition Content:
- Physical prototypes of developed hybrid structures.
- Computational prototypes: Animations, boards and source code/definitions.
- Real-time physical/computational model validation rig.

3. Background

This cluster assembles professionals from academia and practice within the fields of architectural design and structural engineering. Our motivation for proposing this cluster lies in a shared interest in finding solutions to computational challenges through active, open and interdisciplinary collaboration. We hope that by expanding this network through the cluster we will provide new perspectives and insights from other related disciplines.

A wide range of form-finding tools exist including the direct stiffness method (6), spring-based modelling (1), force-density methods (8) and projection-based methods (4). Each have their strengths with suitability varying for different structural systems and design objectives. Despite continued advances in software interoperability, more often than not creative ideas generated in geometrically flexible digital design environments (such as Grasshopper) must still be

Fig 4: Photo of Arborescence, a bending-active 'light' sculpture floating in an Amsterdam canal (Loop.pH/Ramboll UK 2014).

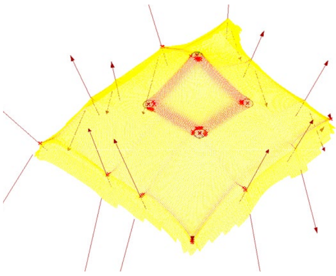

Fig 5: Structural analysis of Noah's Prism, a cable-net canopy, using Kangaroo2 (Loop.pH/ Format 2015).

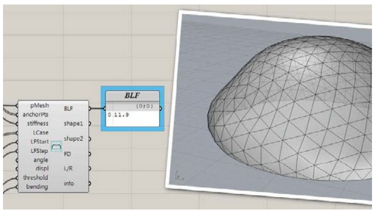

Fig 6: Non-linear buckling analysis of a shell using a compiled plug-in which implements Kangaroo2 (Cecilie, Bath 2015).

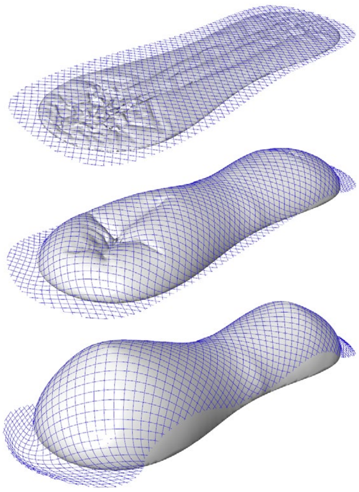

Fig 7: Pneumatic erection of a strained grid shell using Kangaroo2 physics. (KET 2015)

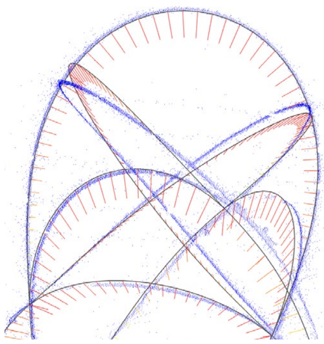

Fig 8: Validation of bending behaviour with laser scanned physical model (CITA/KET 2015)

laboriously exported to specialist engineering packages in order to evaluate their performance to a high level of precision.

This multi-step process can restrict the creative "sketching" process and does little to inform the designer during conception phase, i.e. when it really counts. In the case of structures, performance evaluation using the traditional direct stiffness method associated with FEM, while accurate, requires often cumbersome data exchange and can be computationally slow to analyse (due to the inversion of large matrices with high DOFs). Kangaroo 2's projection based dynamic relaxation solver on the other hand is able to predict the structural behaviour for a growing set of structural elements (rod, beam, cable, membrane…) with equal precision but at a fraction of the time and, most importantly, in the same digital design space as the geometry conception. Furthermore Kangaroo2 comfortably deals with large deformations, as found in membrane, cable and bending-active structures.

Since its inception, Kangaroo has become well established as a design and optimisation tool. Kangaroo (like many other Grasshopper plugins) is now an essential tool in the inventory of many architects and designers facilitating the design of many real and digital projects. Kangaroo2's extension to accommodate real-world mechanical properties now opens yet another door in the canon of architectural design modelling and differentiates itself from many other "physics-free" form-finding methods for which there is often a detachment between digital ideas and their feasibility as real building systems on a larger scale.

4. Research methods

1) Theoretical Grounding:
It is key that participants grasp the fundamental theoretical principles that underlie the methods used in this cluster. Notably the structural mechanics involved in the design of form-active hybrids and how this relates to projection based dynamic relaxation with Kangaroo2. This will be presented in mini lectures in the beginning of the week and expanded upon in support sessions in the evenings.

2) Mechanically Accurate Modelling with Kangaroo2:
The initial computational modelling methods explored in the cluster will be centered around the use of the standard suite of Kangaroo2 components with parameter values calibrated to represent real-world mechanical properties. This will introduce participants to the general modelling pipeline (fig 9) and allow them to start exploring different hybrid designs.

3) Physical Prototyping:
Parallel to the computational modelling, participants are encouraged to ideate through physical modelling and prototyping. Hybrid assemblies will be explored using relatively cheap and simple materials (GRP rods, cables, zip-ties, tape etc.) in combination with connection detailing and membranes made from CNC-cut sheet materials.

4) Real-time Physical-Computational Validation Rigs:
To bridge the computational and physical modelling domains one or two validation rigs will be developed beforehand. These will enable participants to project computational models onto physical models (using a projector in 2D) or vice versa (using a Kinect and the Volvox plugin in 3D). See Fig 8 for example using laser scanner.

5) Advanced Modelling with Kangaroo2:
A primary ambition with the cluster is to demonstrate how to extend the Kangaroo2 plugin by implementing it in scripting components using both GHPython and C#. This will include how to use the library to generate goals and customize your own solver components, how to develop custom goals from scratch and how to script Grasshopper itself for upstream modelling logics.

6) Analysis of Shaped Structures:
Time permitted, we will introduce passive analysis methods within the Grasshopper pipeline and more advanced Finite Element Analysis outside of Grasshopper using SOFiSTiK and the STiKBug plugin.

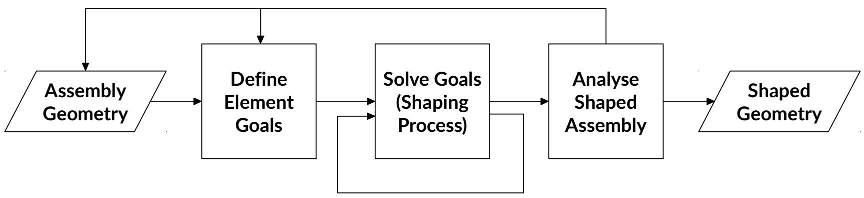

Fig 9: General modelling pipeline for shaping form-active structures with Kangaroo2

5. Schedule	Day 1	Day 2	Day 3	Day 4
Morning	Introduction & context: - Hybrid structures - Structural principles - Modelling principles	Scripting Kangaroo2: - Implementing the library - Calling functions/classes - Customising pipeline	Extending Kangaroo2: - Developing custom goals	- Final prototypes build
Afternoon	Basic Kangaroo2: - Modelling hybrid systems with real-time validation rig.	- Exploratory modelling - Physical prototyping	- Exploratory modelling - Physical prototyping	- Exhibition prep
Evening	- Exploratory modelling - Support/Debugging	- Presentations & feedback - Support/Debugging	- Presentations & feedback - Support/Debugging	- Exhibition opening

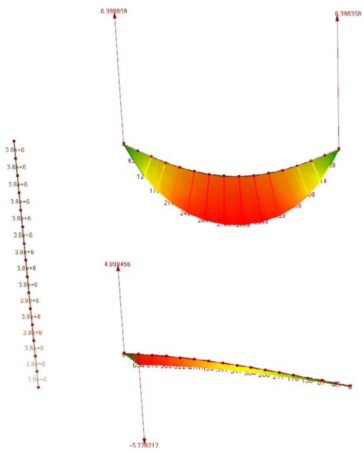

Fig. 10: Mechanically accurate simulation of bending and axial stiffness in Kangaroo2 with live plot of reactions and internal forces/ moments. (KET 2015)

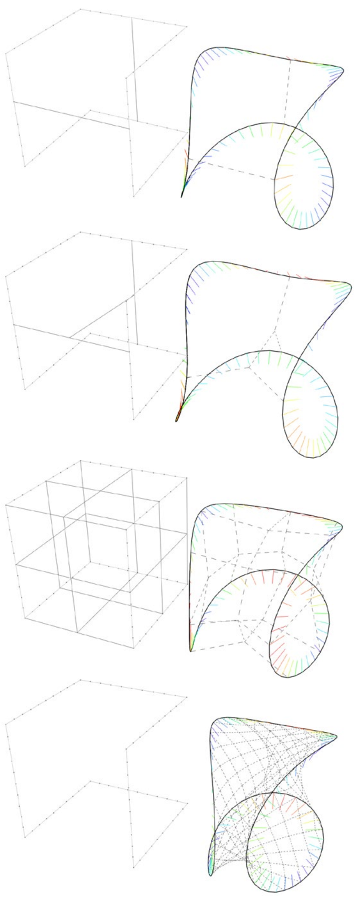

Fig 11: Interactive modelling pipeline which enables live adding, editing and removal of structural elements while solving the shaped assembly (CITA 2015)

6. Requirements

Computational Modelling:
We will be using Rhino 5* and Grasshopper with the Kangaroo 1 & 2, GHPython and Weaverbird plugins for the mechanically accurate modelling of form-active structures. If we have time and there is interest from the participants to interface with an FEM structural analysis package we will be using SOFiSTiK* and the STiKBug Grasshopper plugin. *available as a free trial version.

Physical Prototyping:
For the physical prototyping we will be primarily working with a variety of GFRP and PDA rods (of various diameters). The hybrid structures will be secured together using wire, string, rubber bands and plastic sheeting to act as restraining membranes. The fabrication of these sheet membranes can be done using a CNC cutter. They can be welded using hand held welding pens. Furthermore simple connectors, clips and fixings will also be required.

Validation Rigs:
For the 2D validation rig we will need a couple of projectors. For the 2D validation rig we will require bearing rollers, bolts, string and other simple equipment. Most of this we can prepare in advance and bring with us. For the 3D real-time validation rigs we might use the Firefly or Quokka plugins to interface with the Microsoft Kinect SDK and the Volvox plugin to visualise pointclouds. We will need a couple of Kinects for this.

References

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